DEVELOPMENT OF THREE LEAD ECG MACHINE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Electronics and Instrumentation

By

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Date: **Dr. Samit Ari**

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Table of Contents

ABSTRACT……………………………………………………………………..1

LIST OF FIGURES…………………………………………………………...2

LIST OF TABLES……………………………….……………………….....3

LIST OF ABBREVIATIONS…………………………………..…………......4

Chapter 1 Introduction..…………………………………………...5

1.1 Electrocardiogram………………………………………...6
1.2 Human Heart……………………………………………...7
1.3 Mechanical and electrical Sequence of a Heartbeat……...…8
1.4 ECG waves and QRS complex……………………………..10
1.5 Standard ECG Range………………………………………11
1.6 ECG Electrodes ……………………………………………12

Chapter 2 ECG machine development and Signal Acquisition…....13
2.1 Block Diagram……………………………………………..14
2.2 Instrumentation Amplifier………………………………...…15
2.3 Low Pass Filter……………………………………….....17
2.4 High Pass Filter……………………………………………18
2.5 Gain………………………………………………………..19
2.6 Noise Filtering……………………………………………..19
2.7 Results……………………………………………………..22
2.8 Summary…………………………………………………..23

Chapter 3 Analog to digital conversion and acquisition…………......24
3.1 Block Diagram……………………………………………...25
3.2 Arduino UNO R3…………………………………………...26
3.3 ADC Code…………………………………………………..28
3.4 Digital output………………………………………………29
3.5 Results….……………………………………………………...31

Chapter 4 Conclusion and Future work………………………33
4.1 Conclusion…………………………………………….....34
4.2 Future work……………………………………………35
4.3 References……………………………………………..35

ABSTRACT

An ECG device is used to monitor and analyze the heart activity. In this three lead ECG machine project, we have designed a hardware module for observing ECG signal. The main advantage of constructing a three lead ECG machine is taking measurement during transportation of the patient. The three lead ECG machine requires only patients' limbs to take readings not whole chest area like in 12-lead ECG machine. Although in three lead ECG machine we can observe only two sides of human heart i.e. lateral side and inferior side of the heart. In an ECG machine construction various hardware component needed such as instrumentation amplifier, 741 OPAMP, electrodes, analog to digital conversion (ADC) module, filtering module and display module etc.

The task of collecting various heart signals through the limbs of the patients' is done using electrodes. It could be clamp electrode, adhesive electrode, patch electrode etc. The signals Collected through electrodes are fed to the instrumentation amplifier which basically is a differential amplifier, gets the ECG signals of millivolts from body and amplifies them with internal gain then passes them to filtering circuit for noise removal and setting the upper and lower frequency limitations on the ECG frequency. The signal obtained after the filtering is then again subjected to a gain amplifier for amplifying the final output ECG signals.

The other artifact which influence the ECG signals like frequency distortion, naked wire, power line artifact, environmental problems are taken care for obtaining a good and useful ecg signal using which medical officer can do the analysis of the patients' heart.

LIST OF FIGURES

Chapter 1

1.1 Enthoven electrograph triangle.…………..….…………2

1.2 Human heart chambers………………………………..3

1.3 Detailed heart description……………………………….4

1.4 QRS complex……………………………………………..6

1.5 Adhesive electrode...……...8

1.6 Clamp electrode....………………………...………..8

Chapter 2

2.1 Analog circuit block diagram…………………………10

2.2 AD620 IC and pin diagram……………………………11

2.3 Instrumentation amplifier……………………………..12

2.4 Sallen key low pass filter……………………………....13

2.5 Sallen key high pass filter…………………………...14

2.6 1st order passive filter output …………………………15

2.7 2nd order sallen key filter output……………………15

2.8 4th order sallen key filter output 1……………………..16

2.9 4th order sallen key filter output 2……………………..16

2.10 Implemented hardware circuit……………………...17

2.11 Analog output……………………………………………...18

Chapter 3

3.1 Arduino UNO R3……………………………………….20

3.2 Arduino ADC code ……………………………………21

3.3 Arduino digital output ………………………………...23

3.4 Results…………………………………………………..26

Chapter 4 Conclusion and Future work………………………33

4.1 Conclusion…………………………………………….....34

4.2 Future work……………………………………………35

4.3 References………………………………………………..35

LIST OF ABBREVIATIONS

ECG	-	Electrocardiogram
FFT	-	Fast Fourier Transform
SA node	-	Sinoatrial Node
AV node	-	Atrioventricular Node
ADC	-	Analog to Digital Converter
DC	-	Direct Current (Battery)
OPAMP	-	Operational Amplifier
CMRR	-	Common Mode Rejection Ratio

Chapter 1

INTRODUCTION

1.1 ELECTROCARDIOGRAM

Electrocardiography (**EKG or ECG**) is the medical process for recording the electrical action of the human heart for a certain period of time. An electrocardiogram is a noninvasive, painless test. Body Cells in humans behave like little batteries. These cells have different ion concentrations inside and outside of their membranes which create small electric potentials called biopotentials. This biopotentials is used in obtaining ECG from a persons' body.

The initial technique of ECG signal analysis used time domain method. But this is not sufficient to analyze all the features of ECG signals. So, we needed the frequency representation of the ECG signal. To achieve this, FFT technique is used. But due to unavoidable limitations of this FFT is that the technique failed to express the information regarding the exact position of frequency components in time.

The very first effort for measuring heart signals through lead wire was tried by **Enthoven**. This triangle is used in measuring limb potentials effectively.

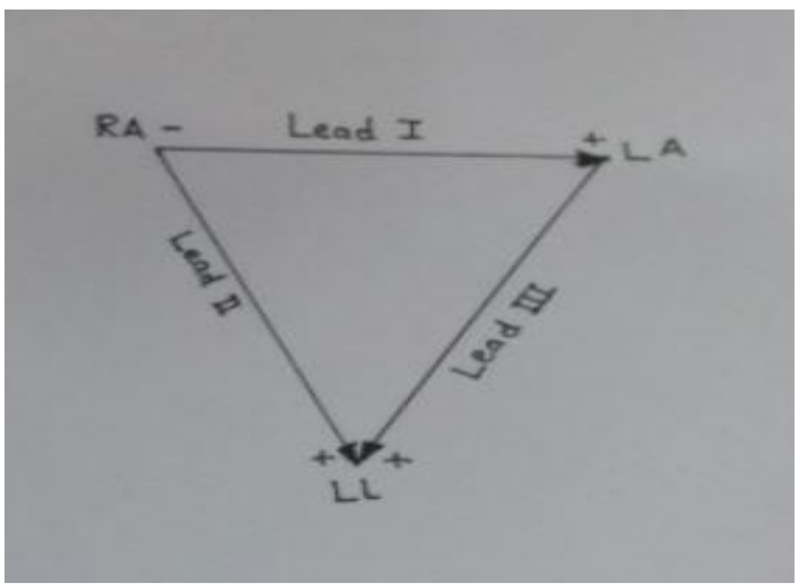


Figure: 1.1

1.2 HUMAN HEART

The human heart mainly has four chambers:
1) Left atrium
2) Left ventricle
3) Right atria
4) Right ventricles

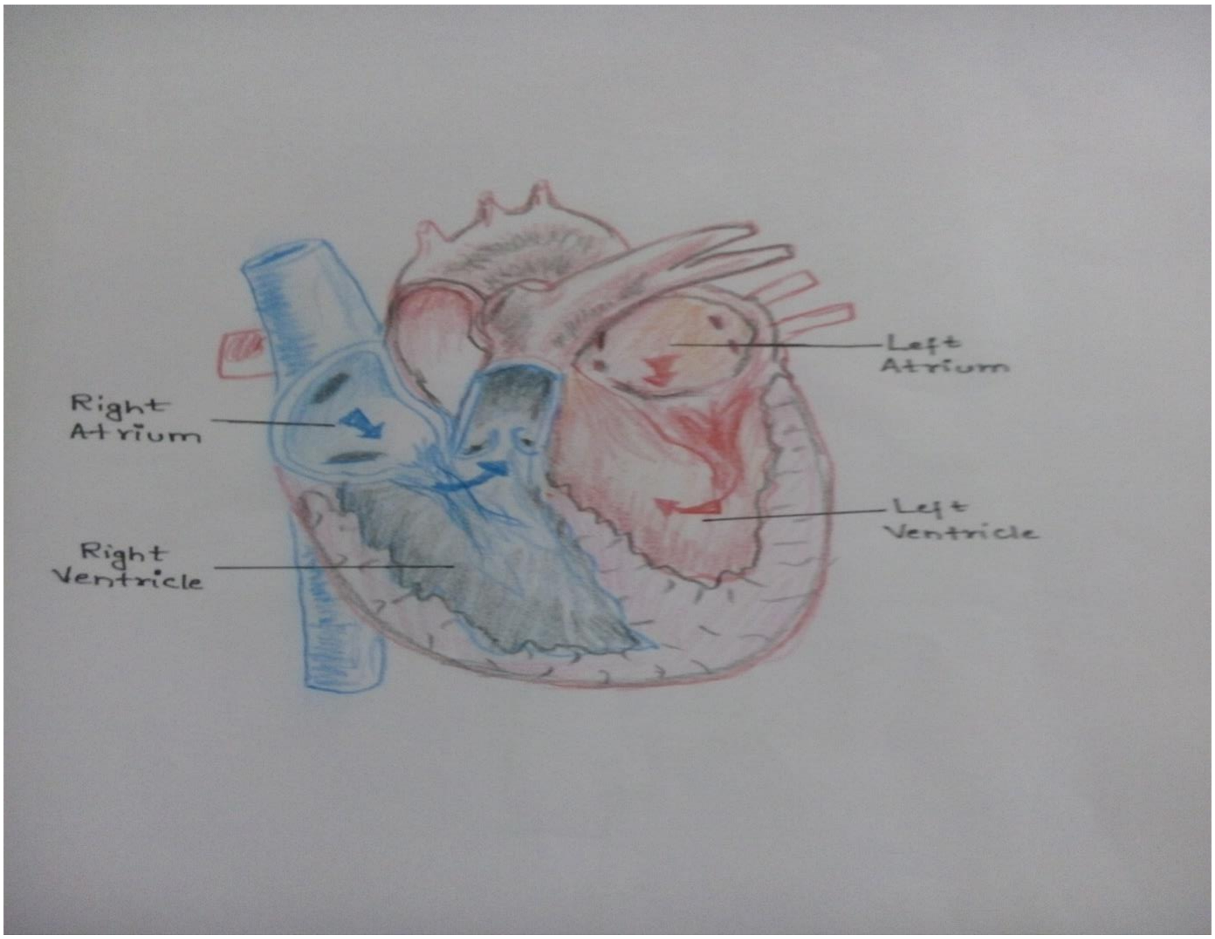


Figure: 1.2

Apart from these four chamber there's also valve present for controlling the blood flow i.e. pulmonary valve, tricuspid valve, aortic semilunar valve and mitral valve. The blue portion of figure represents impure blood flow and red one represents pure blood flow after oxygenation.

1.3 The Electrical and Mechanical Sequence of a Heartbeat

The human heart has a special kind of pacemaker cells which has the property to trigger the electrical sequence of depolarization and repolarization of heart muscles. This special property of heart tissues is called inherent rhythmicity or automaticity. The electrical signal is generated by the SA node and this electrical signal gets spread to the ventricular muscle through particular conducting pathways i.e. internodal pathways and atrial fibers, the AV node, the bundle of His, the right and left bundle branches, and Purkinje fibers (Fig 1.3).

When the electrical signal generated from the depolarization reaches the contractile cells of the heart, they start contracting-a mechanical event occurs which is known as systole. When the repolarization signal reaches to the myocardial cells of heart, they come to a relax mode-a mechanical event which is known as diastole. In this way the electrical impulse signals generated cause the mechanical pumping action for the heart, mechanical events always follow the electrical events.

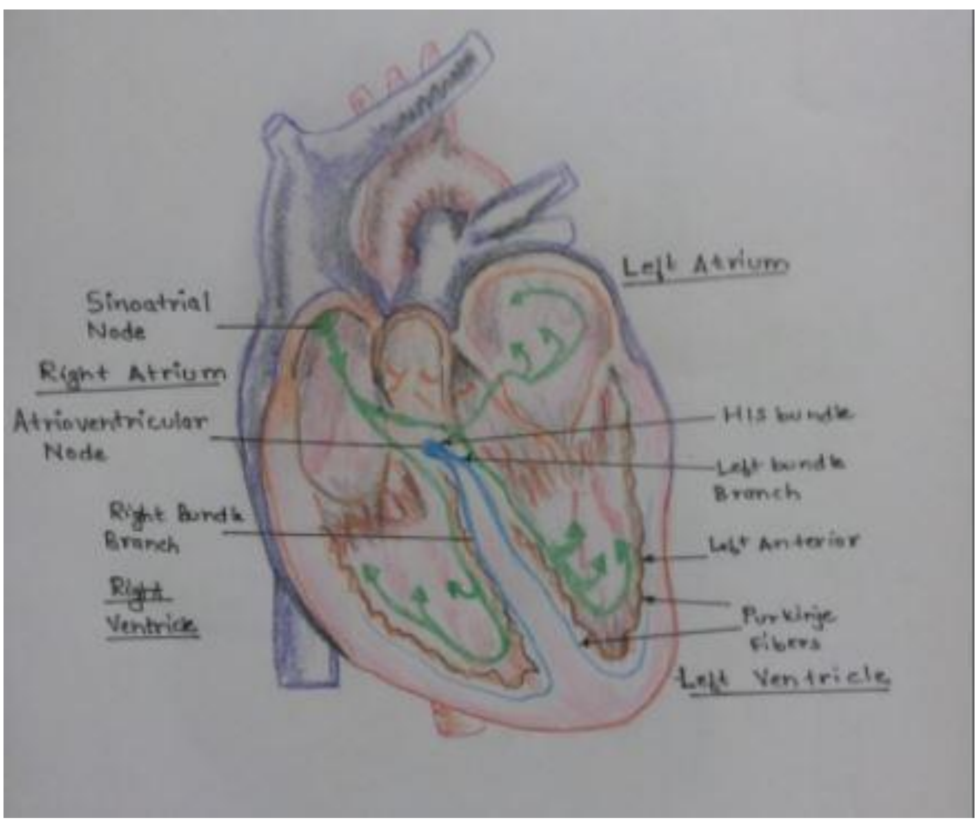


Figure: 1.3

The SA node is the natural pacemaker of the human heart, which initiates electrical impulse signal and mechanical cycle of heart. When the SA node get depolarized, the electrical impulse signal gets spread through the atrial muscles making muscle to contract. So, the SA node depolarization is followed by atrial contraction of heart immediately.

The SA node impulse signal also spreads through the AV node through the internodal fibers of heart. The waves of depolarization does not spread to the ventricles because of presence of nonconducting tissues which separates the atria and ventricles from each other. The electrical signal is delayed by 0.20 seconds in the AV node, when the atria starts contracting, then this delayed signal is relayed to the ventricles directly though the bundle of His, right and through the left bundle branches, and Purkinje fibers of heart. The Purkinje fibers transfer the electrical impulse signals straight to ventricular muscles of heart, causing the ventricles to contract (i. e. ventricular systole). During this ventricular systole, ventricles start to repolarize and enters in a period of diastole.

The heart works as a natural pump which takes the impure blood and purify it by passing it to the lungs where blood get oxygenated and then pumps this oxygenated blood in the whole body system. This pumping action is explained above in words of polarization and depolarization of heart various chambers.

1.4 ECG WAVE AND QRS COMPLEX

The ECG's **QRS complex** is generated by a combined effect of atrial polarization, depolarization and ventricle polarization, depolarization all together.

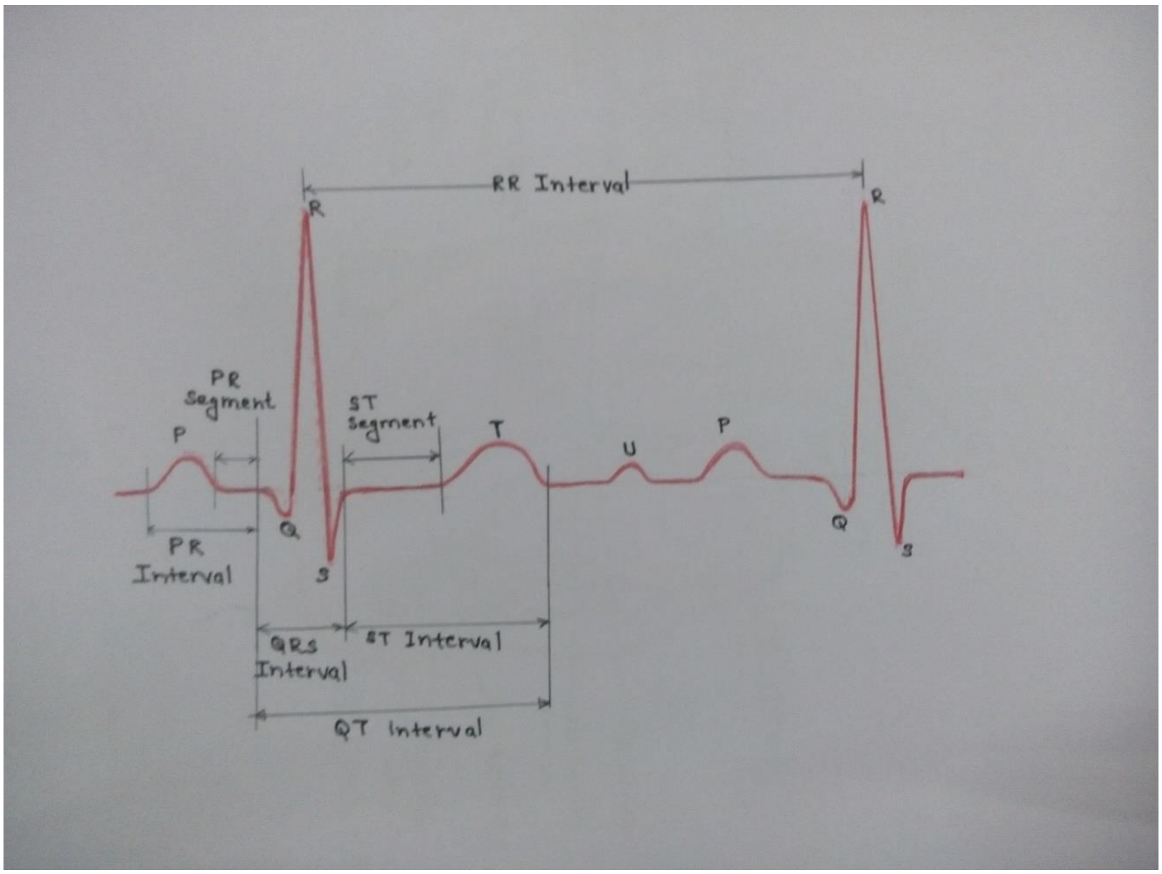


Figure: 1.4

P wave: atrial depolarization

QRS wave: ventricles depolarization

T wave: repolarization of ventricles

1.5 STANDARD ECG RANGE

The various peaks in an ECG complex has a range of amplitudes and a time interval for various segments, intervals and waves , which is summarized in following table:

ECG components	Represents	Duration(s)	Amplitude(mV)
P wave	Denotes depolarization of right as well as left atria	0.07-0.18	<0.25
QRS Wave	Denotes depolarization of right as well as left ventricles	0.06-0.12	0.10-1.50
T Wave	Denotes repolarization of the right as well as left ventricles	0.10-0.25	<0.5
P-R interval	Time from atrial depolarisation to ventricle depolarisation	0.12-0.20	-
Q-T interval	From ventricle depolarization to ventricle repolarization	0.32-0.38	-
R-R interval	Time between successive ventricle depolarization	0.80	-
P-R segment	Time for impulse to reach ventricle myocardium from AV node	0.02-0.10	-
S-T segment	Time during early ventricle repolarization	<0.20	-
T-P segment	Time between ventricle repolarization to atrial depolarization	0.0-0.40	-

All these ranges is defined for a young healthy human and may vary according to the age of the person.

1.6 ECG LEADS

The phenomenon of electric conductivity in the human body involves various charged ions and biopotentials of body. Sensing the bioelectric signals from human body involves interaction with the ionic charges and transducing ionic currents into electric currents required by lead wires and electronic biomedical instrumentation system. This transducing function pf sensing biopotentials is carried out by electrodes that consist of various electrical conductors in contact with the aqueous ionic solutions of the body.

There are various kind of electrodes can be used for ECG measurement such as clamp electrode, needle electrode, floating electrode, adhesive electrodes etc.

Figure: 1.5

Figure: 1.6

In most of the medical places adhesive electrodes are preferred. But, clamp electrode are also used widely because of their long life and robustness. Adhesive electrodes needs to be disposed after 1-2 use, while the clamp electrode has no such limitations.

Chapter 2

ECG MACHINE DEVELOPMENT AND SIGNAL ACQUISITION

2.1 BLOCK DIAGRAM

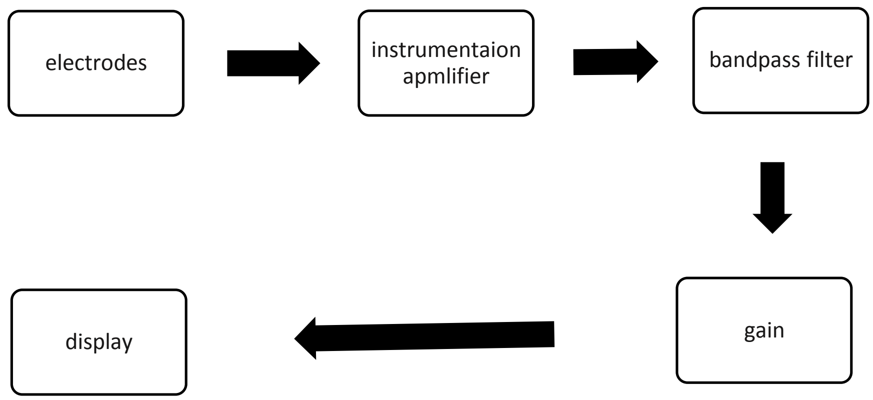


Figure: 2.1

The block diagram contains five blocks which are electrodes- which acquire the biopotentials from the body, instrumentation amplifier- which is fed by electrodes and it amplifies the signal with internal gain and provide differential output of the biopotentials, band pass filter- it is a combination of high pass filter (0.5 Hz) and low pass filter (<200 Hz) used for upper and lower frequency limitations on the ECG signals and to remove the noise and other artifact, gain- it amplifies the ECG signal so that it can be visible on the display and at the end display- it could be a oscilloscope or a laptop or a LCD screen to view the ECG signals.

2.2 INSTRUMNTATION AMPLIFIER

ECG signals differ from the microvolt to millivolt range. Because of this very small range, the signals measured are needed to be amplified better interpreted. Most, bio-potential amplifiers are differential amplifiers. Differential amplifiers are used to prevent the noise from the inputs from being not amplified thus yielding a higher integrity ECG signal. Differential amplifiers with such characteristics are difficult to find. Thus combinations of differential amplifiers are used to construct to achieve above requirements, what is called an **instrumentation amplifier**.

In this three lead ECG machine project we have used **AD620** instrumentation amplifier which has following configurations.

Figure: 2.2

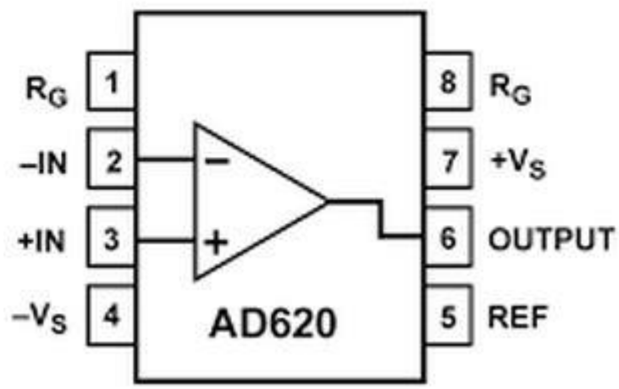


Figure: 2.3

- It has gain set with external resistor (1 to 10,000).
- It has wide power supply range (2.3V to +18V).
- It has 100 dB min. common mode rejection ratio (G=10).

A most commonly used three Op-Amps instrumentation amplifier is shown in Figure 2.4. Three Op-Amps instrumentation amplifiers are widely used because they have over high input impedance, adjustable differential gain and high CMRR.

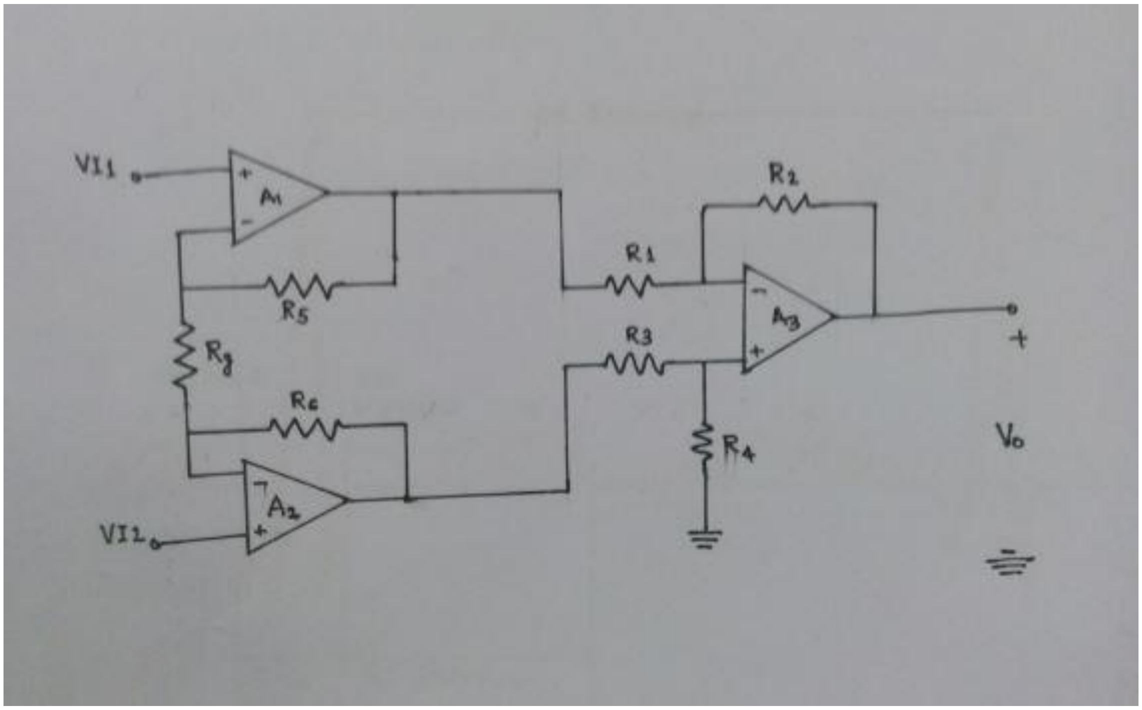


Figure: 2.4

For simplicity, the unknown resistance are assumed to be of same value, R1, R2, R3, R4, R5, and R6 are usually made equal R. The differential gain of the amplifier (Ad = Vo/ (VI2-VI1)) can be obtained by eq. 1.

$$\mathrm{Ad} = 1 + 2\mathrm{R}/\mathrm{Rg} \text{...(1)}$$

The common mode gain of the instrumentation amplifier can be determined by driving both VI2 and VI1 with the same source (e.g. Vicm) and calculating Vo/ Vicm.

$$\mathrm{Ac} = \frac{\mathrm{Vo}}{\mathrm{Vicm}} = \frac{\mathrm{R4}}{\mathrm{R3+R4}} * \frac{\mathrm{R1+R2}}{\mathrm{R1}} - \frac{\mathrm{R2}}{\mathrm{R1}} \text{..(2)}$$

Ac is zero in theory since Ri = R for i = 1, 2…6. But in practice, Ac is not zero because the resistors cannot be perfectly matched. The common rejection ratio (CMRR) in decibels can be calculated by

$$\mathrm{CMRR} = 20\log10\left(\frac{\mathrm{Ad}}{\mathrm{Ac}}\right) \text{...(3)}$$

Thus the instrumentation amplifier is used for ECG measurement purpose.

2.3 LOW PASS FILTER

A **low-pass filter** is a filter which allows the passage signals having a frequency lower than a certain cutoff frequency and blocks the signals with frequencies higher than the cutoff frequency. Here in this three led ECG project we have used a **Sallen-key fourth order filter** with a cutoff frequency of approx. value of **160Hz.**

For develop a fourth order sallen key low pass filter we cascade two second order sallen key low pass filter together. The combined gain of the both second order filter will be multiplication of the gain both the filter has.

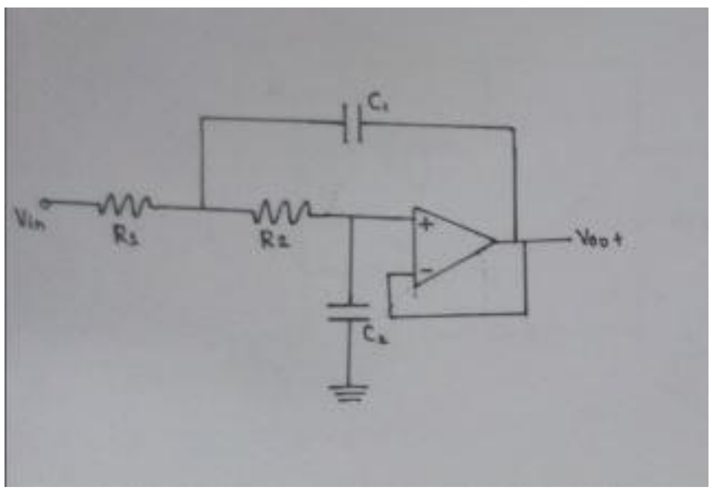


Figure: 2.5

The cutoff frequency of the filter is given by:

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

For getting a 160 Hz low pass filter the values of resistors and capacitors assuming $R_1=R_2=R$, $C_1=C_2=C$.

R= 1MΩ and C = 10µF

The second sallen key filter will also have a gain loop of gain 10. The advantage of 4th order sallen key filter is noise removal and better output of signal.

2.4 HIGH PASS FILTER

A **high-pass filter** is a filter which permit the passage of those signals which has a frequency higher than a certain cutoff frequency and blocks the signals with frequencies lower than the cutoff frequency. Here in this three led ECG project we have used a **Sallen-key fourth order filter** by means of a cutoff frequency of **0.5Hz.**

For making a fourth order sallen key low pass filter we cascade two second order sallen key high pass filter together. The combined gain of the both second order filter will be multiplication of the gain both the filter has. The second filter in cascade has a gain loop of 2400 gain.

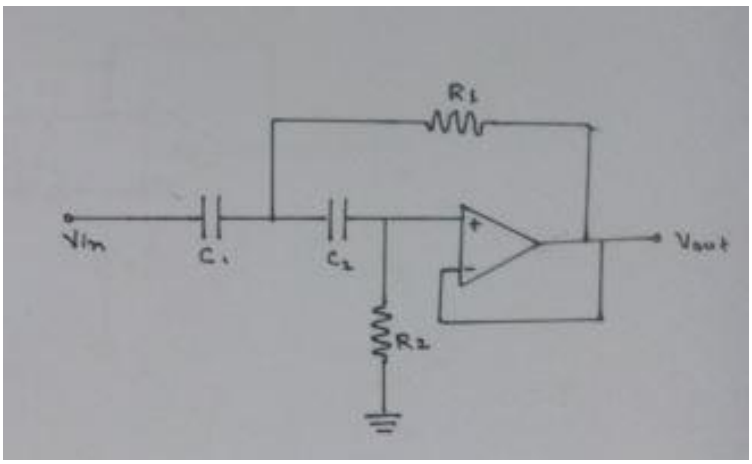


Figure*: 2.6*

The cutoff frequency of high pass filter can be calculated from the given formula

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

For getting a 0.5 Hz low pass filter the values of resistors and capacitors assuming $R_1=R_2=R$, $C_1=C_2=C$.

R= 1KΩ and C = 10µF

The second sallen key filter will also have a gain loop of gain 2400.

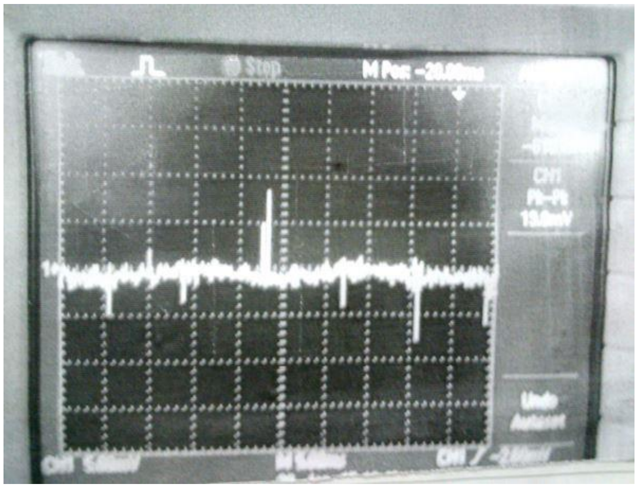
2.5 GAIN

As the instrumentation amplifier has some internal gain but still we need much more gain than internal gain so we used the sallen key filters circuits to get these extra gain to amplify the ECG signals. The sallen key high pass filter of loop gain 10 and then sallen key filter of loop gain 240 and together both the filter provide an overall amplification of 2400 (i.e. 240*10) for ECG signal amplification.

2.6 NOISE AND ARTIFACT

Noise and other artifact influence the ECG measurement and lead us to wrong measurement and cause wrong analysis of heart. During measurement of ECG following problems should be taken care.

- There may be various reasons for distortion of the ECG signal.
- Signal generated from body muscle.
- Signal generated in the epidermis.
- 50 Hz power line interference.
- Offset signals generated by electrodes,
- Lead wire and patients' cable problem.
- Environmental interference etc.



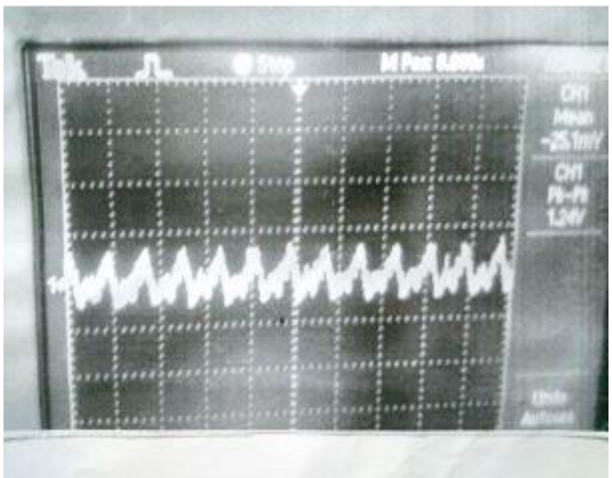


Figure: 2.7 **Figure: 2.8**

These problems are taken care by using filters of high order like we have used sallen key fourth order filter and notch filter and making the environment free from interference in which ecg has to be taken.

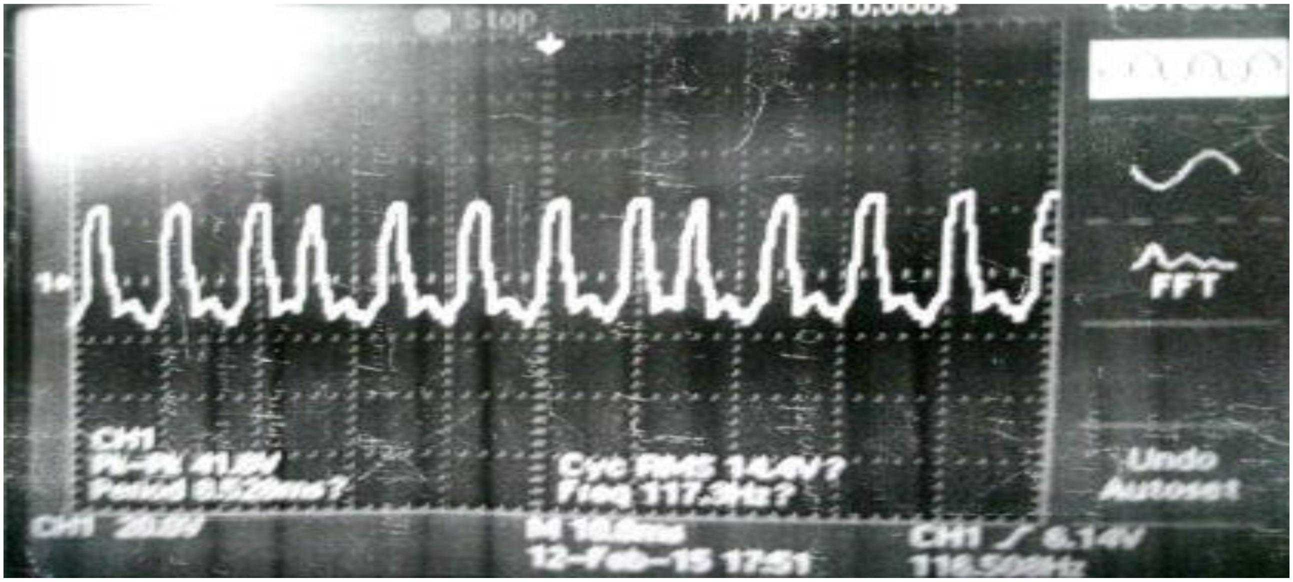


Figure: 2.9

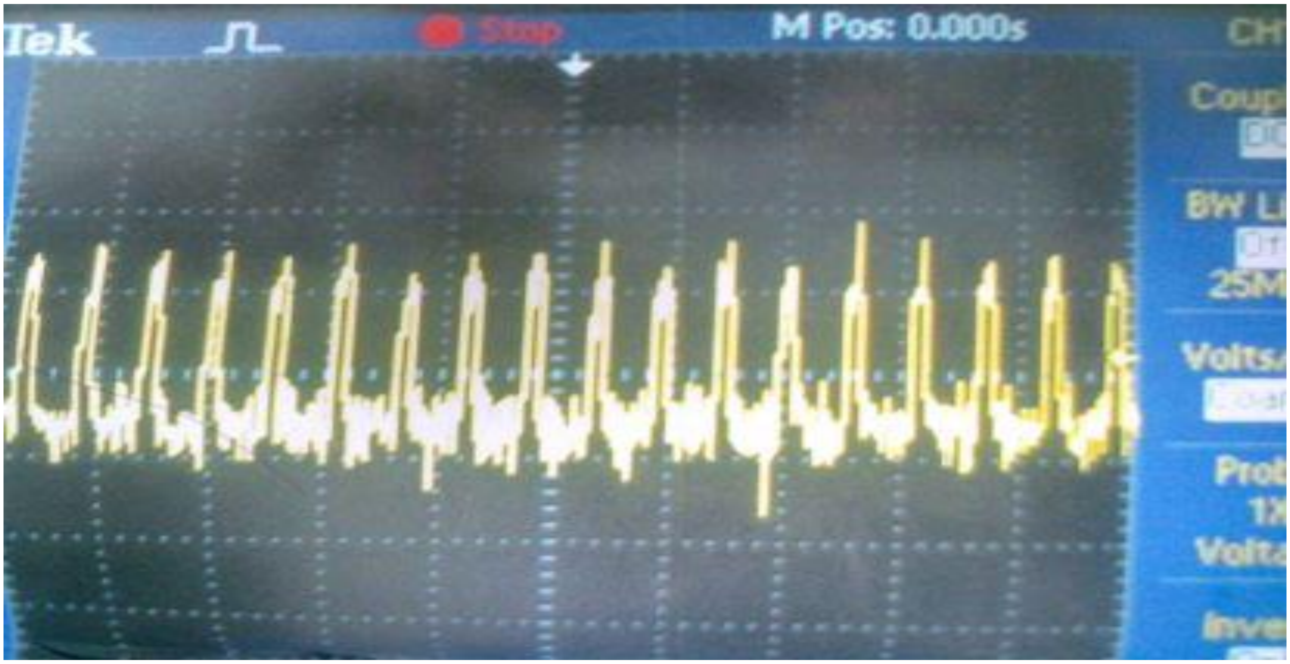


Figure: 2.10

2.7 RESULTS

Starting from the collecting the biopotentials from limbs using the electrodes and feeding them to the instrumentation amplifier (AD620) for the differential gain and the to the filtering circuit to filter off the noises and other noises caused by various artifact and putting upper and lower limitations on the ECG measurement.

After removing all the noises and circuiting problems of the analog circuit, which is as follows:

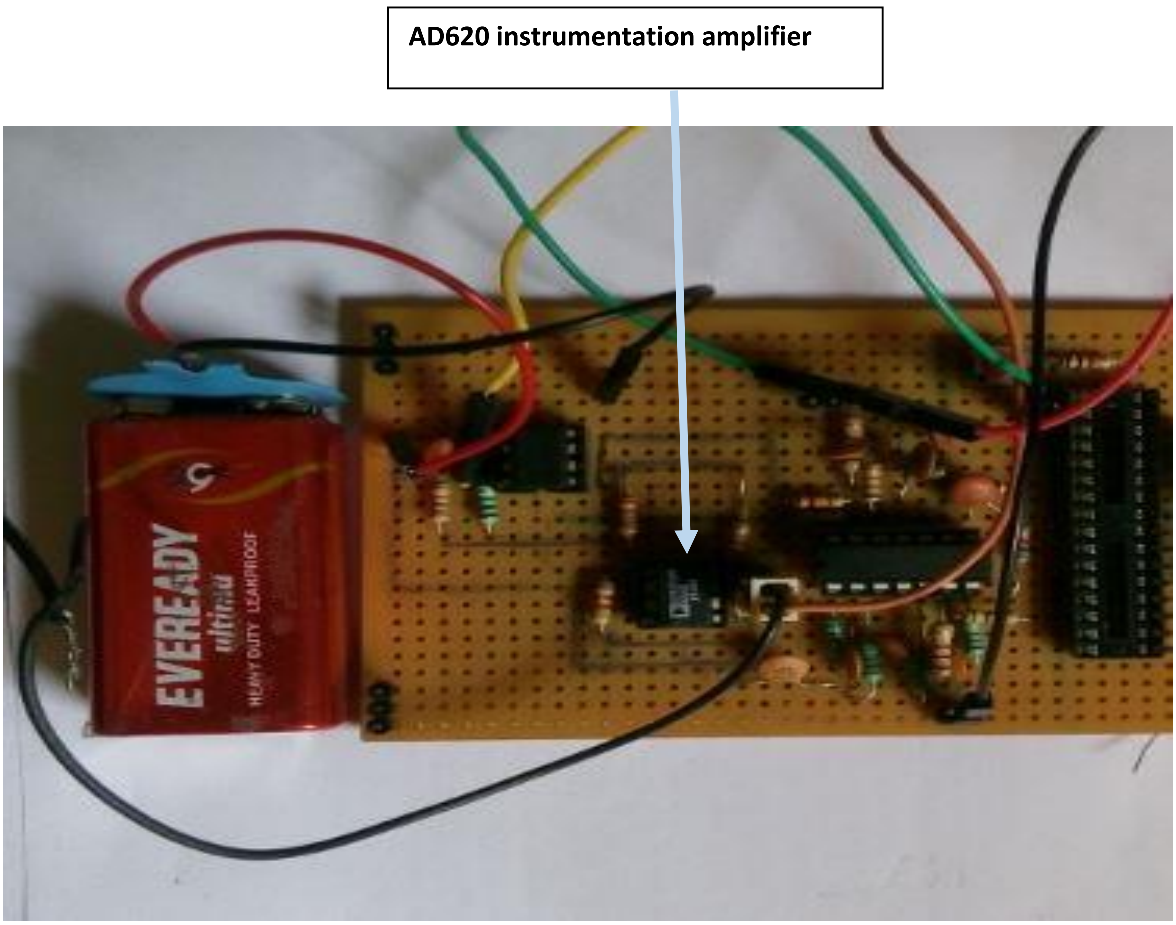


Figure: 2.11

The power supply to the various point is provided by a DC battery source of 9V.

The final ecg signal obtained from the above given analog Ecg circuit is as follows:

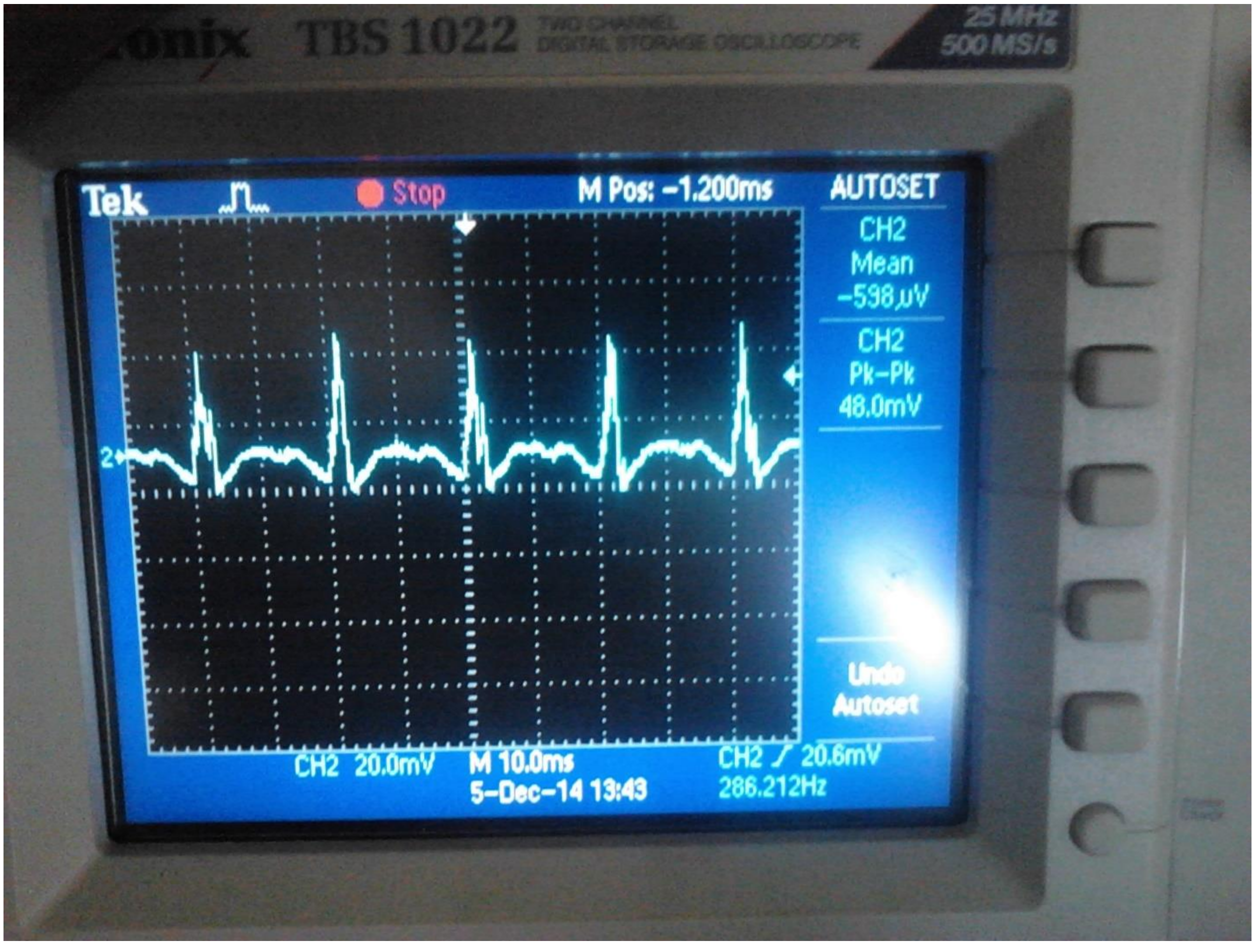


Figure: 2.12

All the waves are clearly visible in this output. The baseline is not very clear due to power line interference and other artifact which could not been removed completely from the hardware circuit. Which can be further reduce to a minimum level by taking care of all the possible noise sources and using some more high order filters.

2.8 Summary

The development of the three lead ECG machine is done using the instrumentation amplifier IC AD620 and its datasheet. The filter in this ECG development is kept at 0.5 Hz frequency of high pass filter while a frequency of 160Hz is kept for low pass filter. These two filters remove the noises and other disturbances from the signal. The final ECG signal is taken to an amplifier gain circuit of gain 2400. This amplified signal is observed on oscilloscope and further used for the analog to digital conversion and data acquisition.

Chapter 3

ANALOG TO DIGITAL CONVERSION AND DATA ACQUISITION

3.1 BLOCK DIAGRAM FOR ADC

We have used ARDUINO UNO R3 to acquire the digital signals. But, we can also use ATmega microcontroller to work as ADC. But in ATmega one has to code the required program and then burn it int ATmega burner which becomes little hectic so ARDUINO UNO R3 is preferred over ATmega.

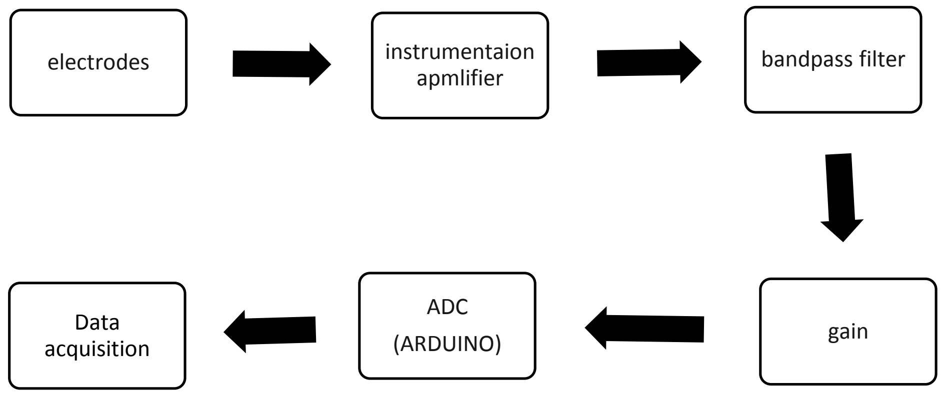


Figure: 3.1

Here in addition to the analog block diagram we have added an ADC module to the block diagram. This ADC blocks takes the analog input from the gain block up to which the rough ECG signal is filtered and amplified. The ADC module converts the analog data and store the acquired data in the database which can be used for plotting or analysis of signal.

3.2 ARDUINO UNO R3

ARDUINO UNO R3 board has inbuilt ADC circuit which is used for acquiring the digital ECG signal on ARDUINO coding software. The ARDUINO UNO R3 coding platform has inbuilt codes for performing the required task, just by specifying the input and output pin in the code.

BOARD:

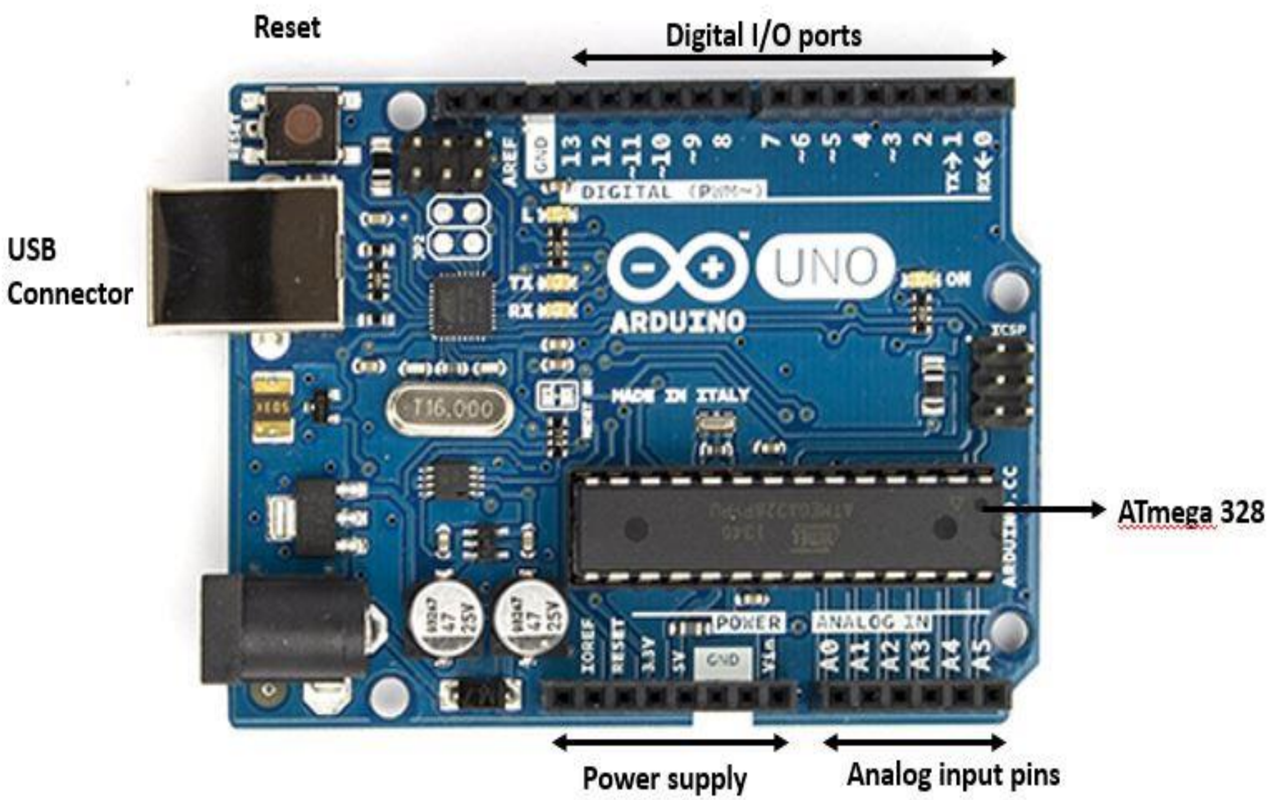


Figure: 3.2

FEATURES:

- It uses microcontroller is Atmega328.
- It has operating voltage of 5V.
- It has input voltage is 7-12V.
- It has 14 digital I/O pins.
- It has 6 analog input pins.
- DC current per I/O pin is 40MA.
- It has 32KB flash memory.
- It has 2KB SRAM.
- 1KB EEPROM
- It uses 16MHz clock speed.

ANALOG CIRCUIT WITH ARDUINO UNO R3:

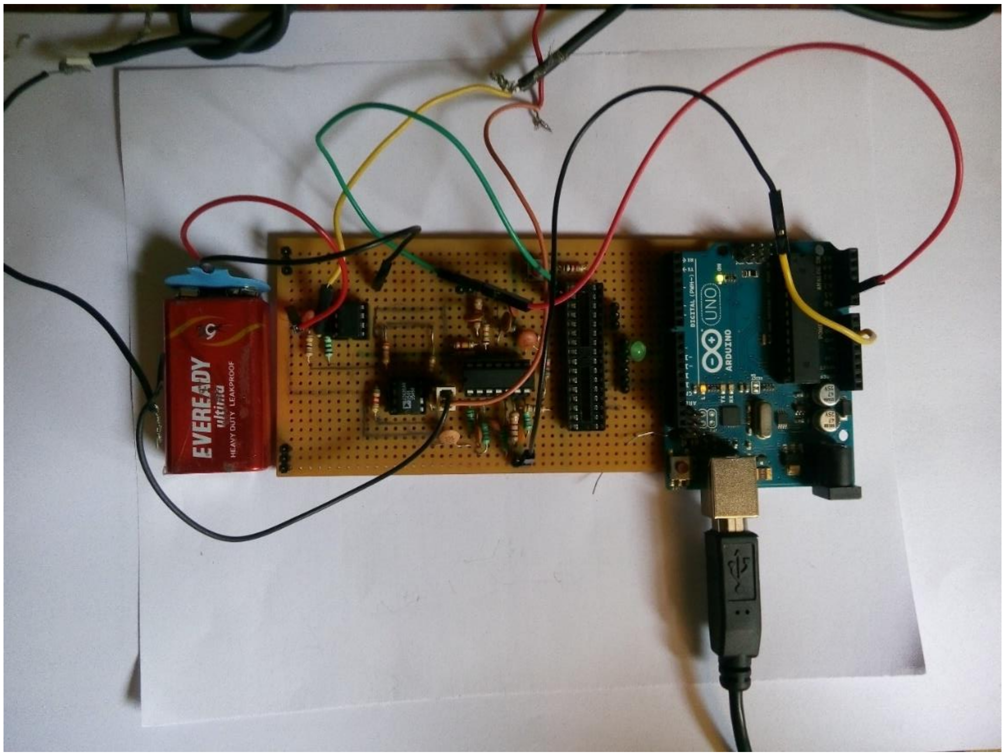


Figure: 3.3

3.3 ARDUINO UNO ADC CODE

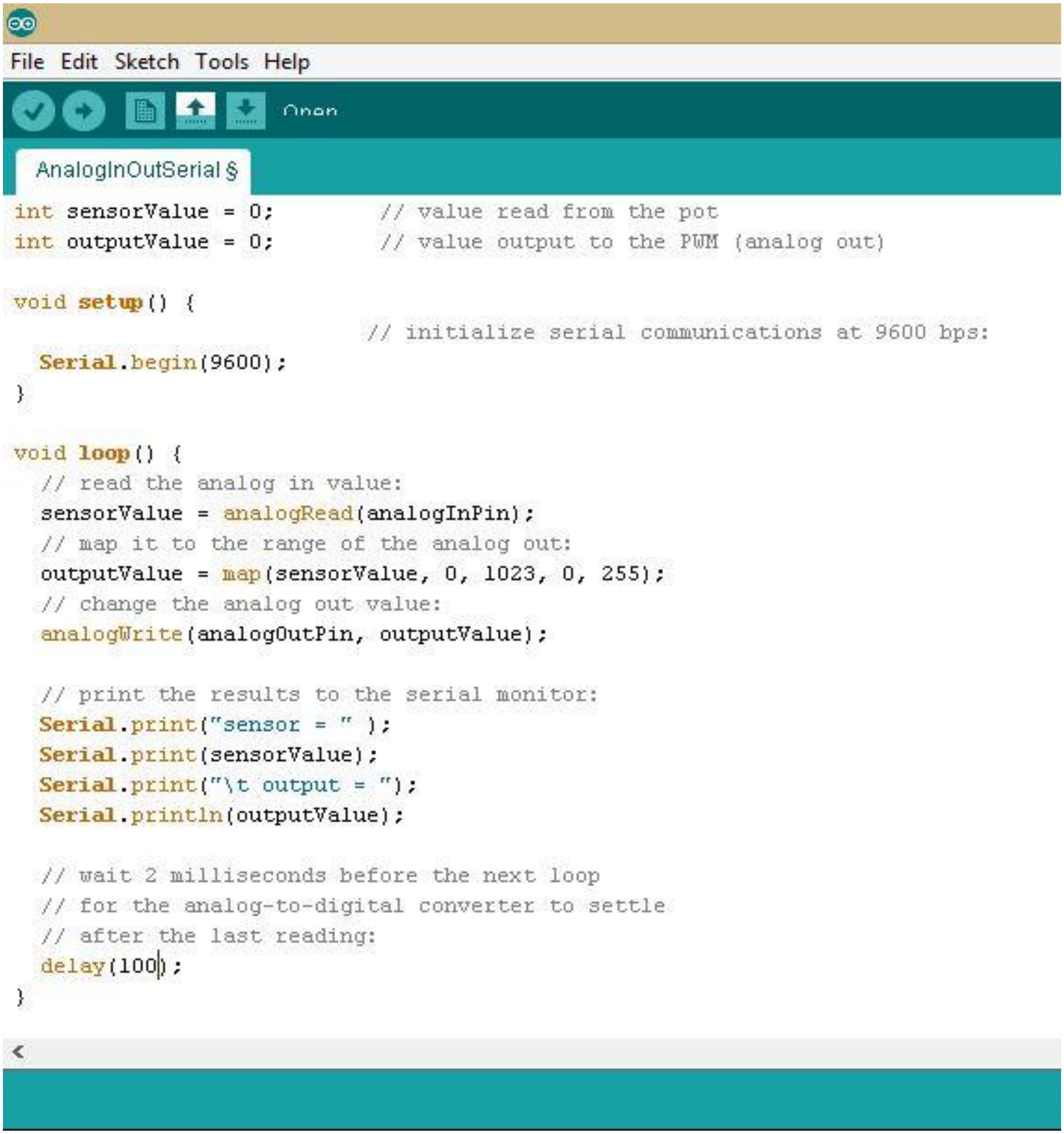


Figure: 3.4

3.4 ARDUINO DIGITAL OUTPUT

```
sensor = 396        output = 98
sensor = 376        output = 93
sensor = 367        output = 91
sensor = 360        output = 89
sensor = 357        output = 88
sensor = 355        output = 88
sensor = 355        output = 88
sensor = 358        output = 89
sensor = 358        output = 89
sensor = 358        output = 89
sensor = 358        output = 89
sensor = 357        output = 88
sensor = 352        output = 87
sensor = 353        output = 87
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 333        output = 83
sensor = 340        output = 84
sensor = 343        output = 85
sensor = 346        output = 86
sensor = 348        output = 86
sensor = 346        output = 86
sensor = 346        output = 86
sensor = 364        output = 90
sensor = 361        output = 89
sensor = 358        output = 89
sensor = 359        output = 89
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sensor = 359        output = 89
sensor = 359        output = 89
sensor = 358        output = 89
sensor = 357        output = 88
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 353        output = 87
```

```
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 355        output = 88
sensor = 356        output = 88
sensor = 357        output = 88
sensor = 356        output = 88
sensor = 354        output = 88
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 350        output = 87
sensor = 351        output = 87
sensor = 354        output = 88
sensor = 359        output = 89
sensor = 356        output = 88
sensor = 356        output = 88
sensor = 355        output = 88
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 353        output = 87
sensor = 355        output = 88
sensor = 356        output = 88
sensor = 356        output = 88
sensor = 356        output = 88
sensor = 352        output = 87
sensor = 352        output = 87
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 351        output = 87
sensor = 355        output = 88
```

3.5 Results

The analog to digital conversion is done using the ARDUINO UNO R3 board and digital data is acquired on the Arduino code monitor. The graph plotted using digital data is not exact same as that of analog ECG signal. The reason may be power line interference during ADC or other artifact causing analog signal distortion which results in digital signal distortion.

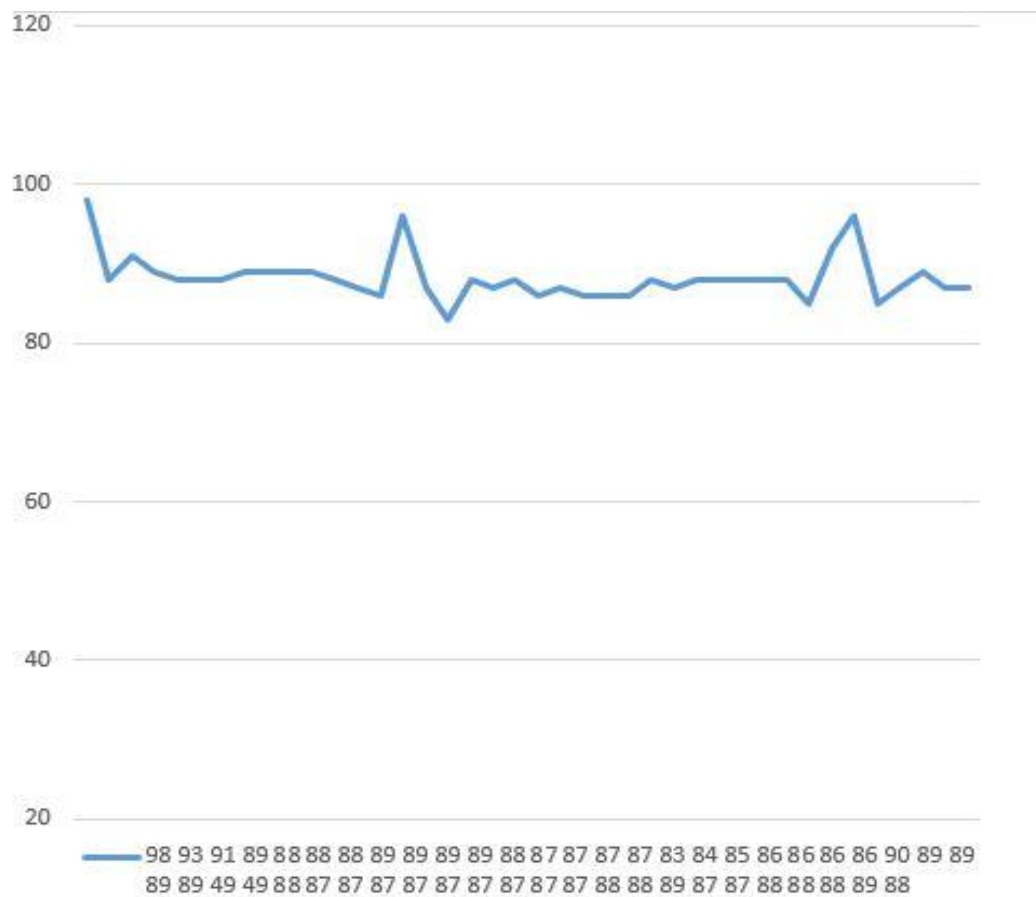

Figure: 3.5

The digital output from the ADC module is plotted on the excel sheet and output plot has the peaks for QRS. The input analog signal has some noise which resulted in twisted baseline after the digitization.

3.6 summary

The analog to digital conversion is done by Arduino Uno board. The input signal to the board is taken from the output of the analog circuit of the ECG machine. The ADC code is uploaded to the Arduino board and then executed. The ECG digital data is acquired and plotted to do the analysis. This digital data can be improved by improving analog circuit. The digitization of the analog signal can be done on some other ADC platform.

Chapter 4

CONCLUSION AND FUTURE WORK

4.1 CONCLUSION

The project on three lead ECG machine hardware implementation is done with some very good output responses and also with some complications along with the output. The noises present in the analog signal caused by various means like, muscle noise, power line interference, other artifact which caused the analog signal to distort and to overcome these problems we implemented the high order filtering circuits, which removes these noises and artifact up to maximum extent and provided us a promising ECG signal. Some noises are also contributed by the rough and wrong soldering of the hardware component which appear across the digital output in ADC module. Before we proceed to the ADC module we take care of all these noises, artifact interferences soldering noises.

We have also got some abrupt digital output which are caused by the noises and other artifact problems present in the analog signal whose digitization we are doing. The baud rate of Arduino Uno R3 can be changed to get the better and precise digital output from the analog signal. We can also get the digital output on MATLAB using the serial communication interfacing and then use various MATLAB filter to remove unwanted signals from the digital output and plot the digital values of the ECG signal.

The overall project of three lead ECG machine is completed to the maximum extent with some scope of future work, to get the better and quality ECG signal. Future work can be done in improving the hardware section and in digitization of the signal like in better soldering, precise filters and ADCs.

4.2 FUTURE WORK

As most of the objective of the project is done but some future work still can be performed for quality ECG signal synthesis. The analog circuit need to be more precise with its component values and their limits of measurement. The removal of noise and artifact is always appreciated in hardware implementation. As the noise and other disturbing signal are removed from the analog circuit we get a promising ECG signal for ADC module. The digital values collected by ADC module can be interfaced with MATLAB where more precise filtering of the digital data can be done.

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